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On the interpretation of redshift dependence of soft X-ray quasar spectra

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Abstract : We examine critically the possible interpretation of the observed correlations of photon spectral index of a sample of X-ray selected quasars with redshift We show that the observed correlations can be attributed to the strong luminosity selection effects in the sample, with little or no intrinsic evolution being required

Keywords : Redshift, selection effects, X-ray quasars

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1. Introduction

Studies of correlations among intrinsic properties of active galactic nuclei (AGN) are important in the understanding of the basic differences between the various classes of extragalactic objects as well as the characteristics of the underlying galaxies and evolution of the intergalactic medium. Our current knowledge of the cosmological evolution of radio galaxies, radio-loud quasars, X-ray selected quasars and starburst galaxies shows that these classes of objects display a remarkably similar power-law luminosity evolution of the $L(z) \sim (1 + z)^3$ up to at least redshift $Z \sim 2$ [1].

Cosmological evolution has also been found for the characteristic linear size of radio galaxies and steep spectrum quasars [2–5] as well as their synchrotron spectra. [6–10]. More recently, Schartel *et al* [11] have shown that the X-ray spectra of X-ray bright quasars appear to be different at low and high redshifts, implying cosmological evolution with spectra being flatter at earlier epochs. This result also suggests that radio-loud quasars show a flatter X-ray spectra than radio-quiet quasars, the former are usually observed at higher redshifts than the latter [12,13]. This is because both power and redshift are strongly correlated in flux-density limited samples (see Figure 1). Correlation of linear sizes and spectral indices with power would produce an apparent correlation between these parameters and z [14,15]. In the present paper, we wish to investigate whether the redshift dependence of the X-ray quasar spectra is real, or an artefact of the luminosity selection effects or evolution mentioned above.

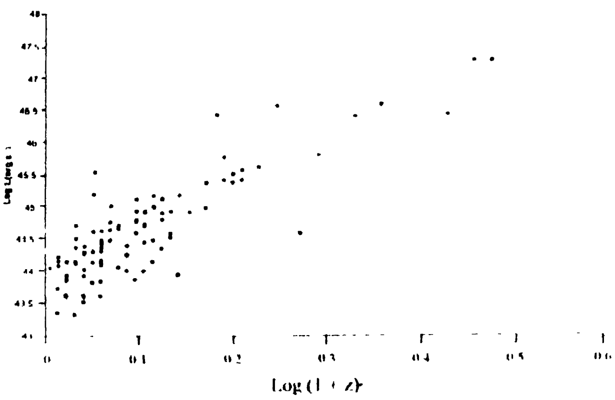

Figure 1. Plot of luminosity *versus* redshift

2. Correlations among the intrinsic properties of X-ray quasars

As mentioned in the preceding section, correlations among the intrinsic properties of X-ray quasars could be used in studying the basic difference between radio-loud and radio-quiet quasars as well as the characteristic of the underlying galaxies. We assume relationships between the photon index (Γ), redshift (z) and optical luminosity (L) at observing frequency (ν) of the form :

$$\Gamma(z) = \Gamma(z_\nu) - m \log(1+z), \quad (1)$$

$$\Gamma(L_\nu) = \Gamma(L_\nu) - n \log L_\nu, \quad (2)$$

and $$L_\nu(z) \propto (1+z)^\beta; \quad (3)$$

and determine the best fit values of m, n and β. Eqs. (1–3) suggest that the combined effects of intrinsic $\Gamma - z$ evolution and a $\Gamma - L_\nu$ correlation would result in an overall apparent $\Gamma - z$ correlation which can be put in the form [14],

$$x = m + n\beta. \quad (4)$$

The value of x therefore can be directly determined from the observed data, and combined with the derived values of n and β, m can be estimated.

The present analysis were performed using the data from Schartel *et al* [11] sample. The sample consists of 102 X-ray bright quasars observed with ROSAT. Out of this number, 55 were classified as radio-quiet while the remaining 47 are radio-loud. The redshift distributions of the two sub-samples appear quite different; 95% of the radio-quiet quasars lie within $0 < z < 0.4$ while their radio-loud counterparts have redshift up to ~2.5. However, the two sub-samples show a continuity in their photon index distribution with luminosity and redshift (see Figures 2 and 3) and were hence combined in the subsequent analysis. The data were organised in five redshift intervals and the mean photon spectral index $<\Gamma>$ and mean power $<L_\nu>$ determined for each redshift interval. The best fit values of the regression parameters x, β and n together with the derived value of m as well as their standard errors were determined by fitting the observed mean value data to eqs. (1–3). The results are shown in Table 1.

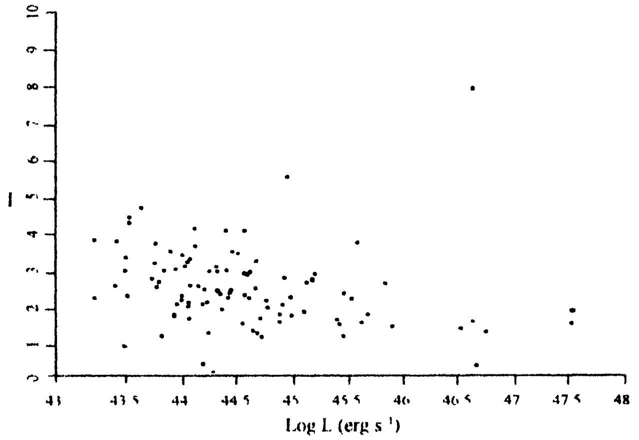

Figure 2. Plot of photon index distribution *versus* luminosity

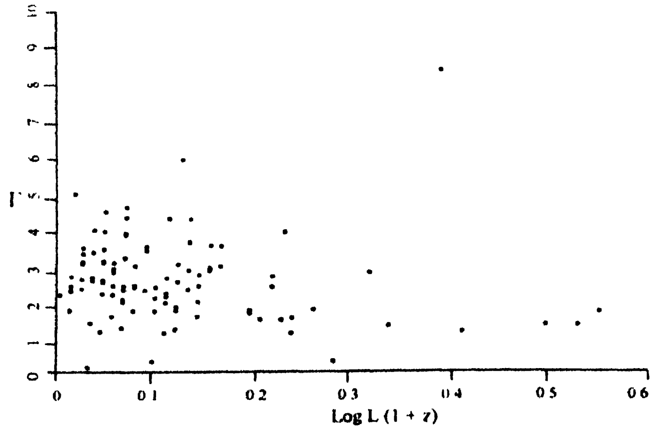

Figure 3. Plot of photon index distribution *versus* redshift.

Table 1. Summary of regression analysis

n	x	β	m
0 21 ± 0 01	1 71 ± 0 39	0 8 ± 0.8	0 03

These results show a strong correlation of $<L>$ with z with correlation coefficient $r \sim 0.99$ which is expected for a flux density limited source sample. In addition, we found highly significant correlations of $<\Gamma>$ with $z (r \sim 0.78)$ and $<\Gamma>$ with L_ν $(r \sim 0.76)$.

3. Discussion and conclusions

We have carried out an investigation of the correlations among the various intrinsic properties of an X-ray bright quasar sample with the aim of establishing whether the observed correlation between the mean photon spectra ($<\Gamma>$) and redshift (z) is real or an artefact of the strong luminosity selection effects present in bright flux-density limited samples. Our results (Table 1) show a strong correlation between (Γ) and z. At first sight, this could be interpreted to imply cosmological evolution in which quasar photon spectra appeared to be flatter at earlier epochs. However, we have shown from the preceding section that after correcting for the apparent $<\Gamma> \sim z$, correlation resulting from the strong luminosity selection effects in the sample, little or no residual redshift effects could be observed (see Table 1).

The present results appear to differ from the previous one [14] based on the radio spectra of a sample of radio-loud quasars and radio galaxies in which it was shown that only ~54% of the observed spectral index-redshift ($\alpha - z$) correlation could be attributed to selection effects, the remaining 46% being intrinsic. Although radio luminosity function evolves at a similar rate as the optical/X-ray luminosity function [1], Peacock [16] has observed that quasar radio luminosity function appears significantly flatter. This may be responsible for the difference between our present result and the earlier one. In fact, our present result sows a steeper $P - z$ slope ($\beta \sim 8$) than was previously obtained ($\beta \sim 4$).

In summary, it has been shown that the observed $<\Gamma> - z$ correlation for a sample of X-ray selected quasars, can be attributed solely to the luminosity selection effects present in the sample.

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